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THE IMPACT OF ROCKY TOPOGRAPHY ON SHRUBLAND HERBACEOUS PRODUCTIVITY IN SEMI-ARID ENVIRONMENTS

ABSTRACT. One of the consequences of soil erosion in arid and semi-arid environments is the emergence of rocky shrublands. While their existence is well documented, gaps exist in our understanding of processes affecting the soil fertility inside them and in their surrounded environment which is crucial for their successive sustainably management. Our aims were as follows: (i) assessing the impact of various parameters (geographical, chemical and physical) on the herbaceous cover in shrublands located in arid rocky areas; (ii) assessing the impact of the rocky topography on the fertility parameters at the inter-patches and surrounded matrix areas. Geographically, the site of study is located in private family farm at Chiran area, northern Negev, Israel. It has semi – arid climate (precipitation 200 mm year-1) with hilly rocky topography. Ecologically the area is sustainably grazed shrubland characterized by patch-matrix patterns.For analyzing the impact of the above mentioned parameters we chose 24 patches belonging to different geographic groups: "Inside the rock", "Adjacent to rock", "Parallel to rock" and "Slopped"). From each patch we took soil and herbaceous biomass samples from predefined locations based on the geographical patterns of each group. Four methodologies were implemented for analysis as follows: (i) comparisons between the actual values; (ii) ranking the differences between the patches" sub-plots; (iii) correlating the soil parameters with the herbaceous biomass using regression analysis; (iv) spatial analysis of the different parameters based on kriging. The results demonstrate that the most influential parameter in the plots inside the patch were the Soil Organic Matter and clay content. The soil moisture in this study did not affect the area fertility. The rocky topography, together with the patch spatial patterns had high impact on the values of the examined parameters, even when compared to the surrounding matrix. Altogether, the presented results indicate that the patch fertility is affected by combination of different soil parameters and the geographic topography of a given patch. Additionally, reciprocal effects between the patches and their surrounding environment are also important determinants of fertility. The techniques and methodologies demonstrated here could be applied to other landscapes as well.

KEY WORDS: slopped patches, adjacent to rock patches, parallel to rock patches, shrublands in rocky arid areas, inter-patch fertility, patches-matrix correlations

INTRODUCTION

Wide parts of the arid and semi-arid environments are defined as shrublands with patchy pattern. It was estimated using satellite imaging that in western Africa these shrublands occupy 16.3% from the total land cover [Fuller& Ottke, 2002]. Some researchers even claim that the state of the above mentioned patches can affect the rehabilitation of arid lands [Aguiar and Sala 1999], and in such a manner may have a dramatic impacts on the area erodibility and water balance [Jones et al 2006] and as a result, the potential for constructing sustainable agriculture systems [Gliessman1998]. Not only the values of the patch parameters such as the patch size [Mor-Mussery et al 2013], patch floral cover [Ludwig et al 2005], and patch structure [Aguiar and Sela 1999] affect a given area and indicate its rehabilitation or degradation state, but the heterogeneity itself could be a good indicator of the patch quality. In support of this claim is the following quote of Ludwig and Tongway [2005] –"Heterogeneity is crucial to the functioning of arid and semi-arid lands and changes in the scale of heterogeneity can be used to study and understand the processes underlying desertification and rehabilitation". Thus, the various aspects of geographical heterogeneity including slope angle [Bennie et al 2008] and stoniness [Bautista et al 2007] affect the functional state of patches. Moreover, the reverse is also true as the patch parameters affect the pattern of the ecosystem [Ludwig et al 2005].

It is important to note that one of the less studied and characterized type of shrublands, mainly due to its high heterogeneity, is the one which found in rocky areas [Omernik and Griffith 2011]. The need to study and model the processes occurring in these areas was emphasized by Xiuqin et al [2011] who recently claimed that one of the effects of soil erosion due to desertification is the creation of rocky topography. Thus, it is important to stress that understanding of these processes will allow sustainable management of such areas. Yet the previous comparative studies assumed that there are no predominant differences inside the patches themselves [for example, Katra et al 2008]. Here, we examine the existence of differences between soil parameters and their impact on the herbaceous biomass in shrublands located on rocky topography.

TOOLS AND METHODS

Site of study

The site of study is located inside private family farm in Chiran area, Northern Negev at the edges of Arad valley (34°59'04"E, 31°19'34"N). The area and its surroundings were heavily grazed till 1992. Afterwards, several family farms were established and the grazing was reduced inside their boundaries [reviewed by Olsvig-Whittaker et al 2006]. These changes caused an increase in the areal fertility [Leu et al. 2014] and its heterogeneity [Ludwig and Tongway 2005]. The site of study is located on south aspect hill slope (elevation is between 450 and 500 m ASL, slope' angle is between 7 – 10°, measured using Magnetic Ploycast Protractor of Empire®*).

The soil is defined as "sandy–clay–loam" based on USDA definitions [USDA 1999]. About quarter of the area has a rocky topography, laid mainly, with orientation perpendicular to hill slope (North-South), from Brecciccetedcuerts, Meishasu formation, Lake Cretaceous origin (definition by Prof. Haim Binyamini, Ben Gurion Univ.), with sizes between 4 and 25 m^2. In the wet season (December – February) the day temperatures were 8.1 – 19.1°C, while the summer temperatures were 21 – 35.3°C (based on measurements between 2000 and 2010).Yearly precipitation amount at the site is between 150 and 200 mm (IMS®, Israel Meteorological Services). In 2012–2014 the precipitation amounts in the farm were recorded by Aviv Oren as follows: 24.10.2013 – 16 mm; 5.12.2013 – 4 mm; 8.12.2013 – 7 mm; 10–14.12.2013 – 119 mm; 30.12.2013 – 16 mm; 15.2.2014 – 5 mm; 8.3.2014 – 23 mm; 12 –15.3.2014 – 81 mm.

Ecologically the area is defined as shrubland (shrub patches occupying 30% from the area and surrounded by matrix, Leu et al 2014], which is maintained sustainably grazed based on Ludwig and Tongway

Fig. 1. Site of study. Photo by A. Mor-Mussery, March 2014

[2000] principles. The patches are occupied mainly by species belonging to shrubs, geophytes, perennials herbs groups as follows: *Thymelea hirsute* (Thymelaeacae*), *Asphodelus ramosus* (Alliaceae), *Echinops polyceras*, *Artemisia sieberi* and *Artemisia arborescens* (Asteraceae), *Anchus astrigosa* and *Echium angustifolium* (Boraginaceae), *Salvia lanigera* (Lamiaceae), *Ferula communis* and *Pituranthos tortuosus* (Apiaceae), *Noaea mucronata* (Chenopodiaceae), *Sarcopoterium spinosum* (Rosaceae) and *Astragalus caprinus* (Fabaceae).

The herbaceous flora in the patches included mainly the following species***: *Avena sterilis*, *Stipa capensis* (Poaceae), *Calendula arvensis, Centaurea hyalolepis, Chrysanthemum coronarium*, *Negev Chamomile***(Asteraceae), *Carrichtera annua* and *Reboudia pinnata* (Brassicaceae), *Onobrychis crista-gall* (Fabaceae)

* *In brackets – the family name*

** *Definition in doubt*

*** *Based on the sampling date (additional species were observed later in the season)*

The definitions of perennials were done by Dr. Bert Boeken and those of annuals by Prof. Pua Bar (Kutiel), both from Ben Gurion University of the Negev, Israel.

Sampling was implemented in March 2014 and additionally at September 2014, for patch 10.

Note. The tools and software do not represent the authors' preferences.

Sampling scheme and lab analysis

For separating between the patchy and the matrix parts of the tested rocky shrubland we used the definitions described in Mor-Mussery et al [2014a]. From these patches we selected ellipsoid ones settled by perennials (those settled by nests were omitted, Mor-Mussery et al 2014a] located on hill slope and adjacent to rocks. Particular for this study the following groups were studied: "Inside rock" – Patches located in the middle of plain rock without soil strips connected to the un-rocky area; "Slopped" – Patches located on hill slope far from rocks; "Adjacent to rock" – Slopped patches with rock in their north or south edges; and

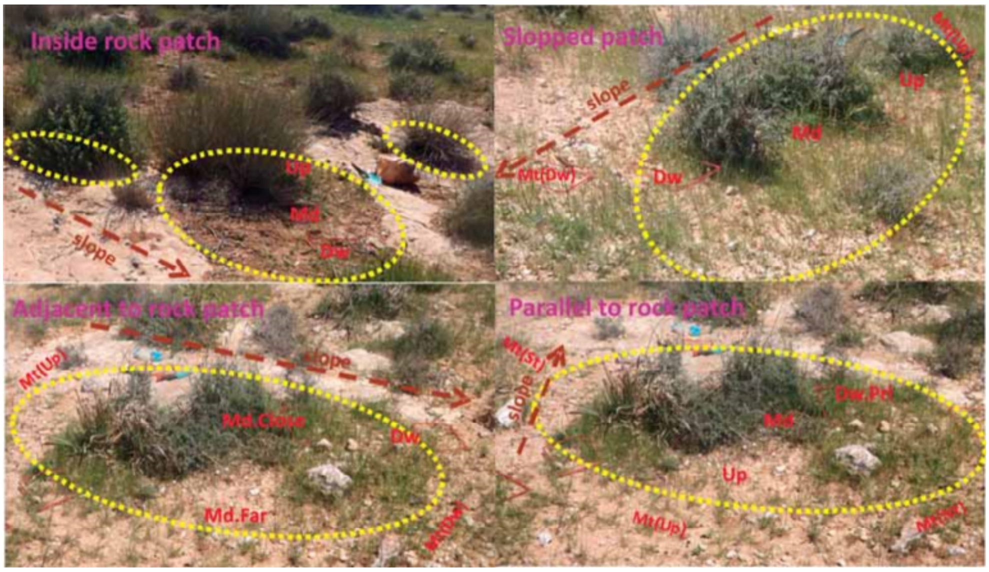

Fig. 2. Representative patches and their sub plots for the different studied groups. Photo by A. Mor-Mussery, March 2014

"Parallel to rock" – patches with rock on their lower part (their west edge).Total of 24 representative patches were chosen for the analysis, as follows: Ten for the "Inside rock", four for the "Sloped", four for the "Adjacent to rock" and six for the "Parallel to rock" group. Each patch was given a serial name.

Per each patch type a descriptive sub-patch sampling scheme was fitted, together with their adjacent matrix (the locations were chosen conceptually based on the water stream to patch – and out of it, [Aguiar and Sala, 1999]). The patches' sub-plots were abbreviate as "Pt" and the Matrix ones as "Mt". The subdivision was as follows:

For the "Inside rock" group, three parts were fitted*: patch upper part – "Pt(Up)", middle – "Pt(Md)" and lower – "Pt(Dw)".

For the "slopped" group five parts were defined: patch upper part – "Pt(Up)", middle – "Pt(Md)" and down – "Pt(Dw)", the adjacent upper matrix area – "Mt(Up)" and for the lower – "Mt(Dw)".

For the "adjacent to rock" group six parts were sampled: patch upper part – "Pt(Up)", the middle part which is close to rock – "Pt(Md. Cls)", the far one – "Pt(Md.Far)", lower – "Pt(Dw)", the adjacent upper matrix area – "Mt(Dw)" and the lower – "Mt(Up)".

For the "Parallel to rock" group six parts were defined: patch upper part – "Pt(Up)", middle – "Pt(Md)", the lower part which is adjacent to the rock – "Pt(Dw.Prl)", the adjacent upper matrix area – "Pt(Up)"*, for the upper matrix – "Mt(Up)", south – "Mt(St)", and for the north – "Mt(Nt)".

** Due to research limitations, we excluded the analysis of the "Pt(Up)"*

For the fourth analysis we chose representative patch belonging to "Adjacent to rock" group (Numbered as "10") which was characterized by high spatial heterogeneity (topographically, closeness to rocks, settled shrubs, stoniness, etc.). In addition to the samples taken based on this group's predefined six parts, three (five in the second set) samples were taken all over the area in a random manner. The sample plots were documented relatively to the attribution point (marked as straight angle on adjacent rock) (Fig. 6, small frame).

From each patch part both soil and herbaceous biomass were taken randomly at 26.3.2014, and treated as described below. Herbaceous biomass was taken using 20X20cm iron frame, dried 48hours at 65° and weighed (values in Kg m^{-2}). Soil samples were taken from soil surface till 15cm depth (root zone of annuals in arid areas, [Fischer and Turner 1978]). The soil samples were dried at 105°C to get rid of the soil moisture. Parts of the soil samples were burned at 400°C to determine the Soil Organic Matter(SOM) content based on protocols of Sava [1994]. The other parts of the soil samples were analyzed for mechanic content composition based on "Stocks law" and the protocols of Klute [1986], expressed in Silt and Clay percent from dry matter.

In order to assess the effect of stoniness on herbaceous cover inside patch Nr. "10",elevensoil samples of10X10cm size from surface till 15cm depth were taken at September 2014, dried at 105°C overnight and weighed. Afterwards, the soil was sieved using 11.4 mm and 0.36 mm diameter iron nets. This resulted in two fractions*: one of stones with Dm_{max}<11.4 mm and the other ofDm_{max}0.36-1.44 mm*. The stones fractions were weighed and expressed as percent from the total dry soil [Sheng 1990]. Afterwards the soil was mixed with 1Litter of water and the floated organic natter (roots, litter, etc.) was gathered, dried overnight, and weighed. The results were expressed as percent from the dry soil.

* *The filtering ability is based on the stone's maximal diameter [Sheng 1990].*

Data analysis

One of the biggest challenges of this work was choosing the most appropriate type of data analysis for detecting the differences between the patches groups' sub – parts in this rocky shrubland and identifying the soil parameters affecting the herbaceous biomass. For this purpose, we have constructed a four layer analyses system.

The first type of analysis was aimed at exploring the differences between the patches and their surrounding matrix. With this in mind, four parameters were defined and calculated as follows:

"Inter Patch Heterogeneity" – calculated by dividing the range between the maximal and minimal values by the minimal value. For example, patch Nr. 7 which contains the SOM values between 4.51 and 7.43 has the' Inter Patch Heterogeneity' value of ~51% (the calculation – 100*(7.43-4.51)/4.51). The values per each patch group were summarized and the resultant ranges were presented.

"Patch vs. Matrix" – was calculated by subtracting the averaged values of the patch sub-parts from those of their surrounding matrix. The results were calculated as percent from the patch average value. As example, for patch Nr. 20 with the averaged herbaceous biomass of 0.032 Kg m^{-2} and the surrounding matrix samples of0.08 Kg m^{-2} the calculated 'Patch vs. Matrix value was 82%. The results of all patches belonging to the studied group were documented and the ranges (extreme values) were presented.

"Patch vs. Matrix(Up)" – calculated by subtracting the upper matrix value from the averaged patch value. The results were presented relative to the patch average value. The "Patch vs. Matrix(Down)", "Patch vs. Matrix(North)" and "Patch vs. Matrix(South)" were calculated similarly with respect to the noted matrix. Negative results represent higher values in the matrix than those found in the patches (for example, for the silt concentration the difference in range between the patch and its surrounding matrix was: "$_{(-)}$78-33%", which means that in one extreme case the average value in the patch was 33% higher than that of the matrix, while at the other side of the range it was lower by 80%).For emphasizing and differentiating the negative values from those found in the range, they have been marked by lower-case brackets, as follows: "$_{(-)}$".

The second analysis was aimed at defining the heterogeneity inside the groups of different patches. The analysis is based on ranking the actual values according to their serial order of magnitude. For example, in Patch Nr. 11(belonging to "Adjacent to rock patches") the SOM values were as follows: "Pt(Up)" – 5.61, "Pt(Md.Cls)"-7.65, "Pt(Md. Far)"-6.19, "Pt(Dw)"-6.07, "Out(Dw)"-5.91 and "Out(Up)"-4.09%. Based on these values, the rankings were: "2", "6", "5", "4", "3" and "1", respectively. The ranks belonging to each patch part were averaged for each group and columns graphed. In such a way we illuminate differences between the patches due to the local geomorphological, ecological and other circumstances.

Note, in the case of patch belonging to the "Inside rock patches" group, the matrix value was calculated as the average of the whole matrix samples, due to the difficulty in defining the stream routes on the rock to the patch and out of it.

The third analysis which aimed at studying the relationship between the soil parameters and herbaceous biomass was done by intersecting their actual values based on linear trend line (separately for the inter-patches and the matrixes).

The integrative forth type of analysis was carried out in patch Nr. 10 by making spreading maps of the all above mentioned parameters (soil and herbaceous biomass ones) from the first set together with the stoniness, and soil litter parameters from the second one. The characteristics of the patch Nr. 10 were as follows: funnel shape, slope located, rock bordered from its north and south sides, area of ~8m^2, the slope angle range 18-26^o and in the west edge a strip width of 0.4m with 30^o angle settled with *Pituranthos tortuosus*, *Noaea mucronata* and *Asphodelus ramosus* in its edges (except the west side). The first set was based on nine sampling plots taken in spring (March, 2014) and 11 in the summer (August, 2014) (Fig. 6a). These spreading values maps were visually compared to the herbaceous biomass cover one and the shrub locations as presented on the attached photo. The values spreading maps were prepared based on kriging analysis using GSWin® ver. 3.3[Gamma design 2013]. The definitions for the analyses were: semi-variogram based on spherical model, isotropic axis orientation, block kriging, and seven equal continuous categories [for further reading, Mor-Mussery et al 2014b; Turner 2005].

RESULTS

Even from the first sight it is clear that the differences inside the patches ("Inter-patch" parameter) with relation to all the examined factors, including SOM, are very high (even reaching above ten times difference). These results are noticeable mainly when they are compared to the differences observed between the surrounding matrix of the examined patches ("Patch-matrix(Sur)" parameter) which were found to be only several fold. Although high heterogeneity was present, several trends were observed. The lowest values were at the slopped patches group. The factors with the maximal differences were the herbaceous biomass, silt, and clay, while the most different groups were the "parallel to rock" and "adjacent to rock". Higher values in the matrix as compared to the patches belonged to the soil moisture, silt and clay factors.

The application of the more precise analysis (differentiating the matrix plot into the upper, lower parts, northern and southern sub-plots) showed that there were no differences between the north and south matrixes with relation to the patch average values of all the factors. The differences between the patches with regard to the herbaceous biomass, SOM and Silt were higher in case of the upper matrix when it was compared to the lower one (due to the sampling scheme, this comparison was done on patches belonging to the groups "Adjacent to rock" and "slopped"). The values were higher in the lower matrix with relation to the soil moisture factor. The clay values showed

Table 1. The differences in the soil and herbaceous biomass parameters between the inter-patches and their surrounding matrix

Parl. rock	Adj. rock	Slopped	Inside rock		
62–666%	132–1075%	125–199%	63–4,445%	**Inter-patch**	**Herbaceous Bm.**
66–94%	70–85%	33–90%	–	**Patch-matrix (Sur)**	
48–82 (St)%	57–90%	48–84%	–	**Patch-matrix (Dw)**	
54–99 (Nt)%	81–84%	(–)3–96%	–	**Patch-matrix (Up)**	
4–87%	15–42%	10–44%	20–405%	**Inter-patch**	**Moisture**
–78–29%	9–31%	(–)12–38%	–	**Patch-matrix (Sur)**	
(–)23–34 (St)%	18–42%	(–)23–85%	–	**Patch-matrix (Dw)**	
(–)133–34 (Nt)%	(–)1–57%	(–)9–27%	–	**Patch-matrix (Up)**	
11–101%	15–133%	13–51%	51–98%	**Inter-patch**	**SOM**
3–31%	14–26%	(–)10–20%	–	**Patch-matrix (Sur)**	
(–)8–30 (St)%	7–33%	(–)28–20%	–	**Patch-matrix (Dw)**	
(–)17–32 (Nt)%	14–36%	(–)13–22%	–	**Patch-matrix (Up)**	
35–1074%	117–173%	18–449%	68–195%	**Inter-patch**	**Silt**
(–)149–41%	(–)41– (–)5%	(–)78–33%	–	**Patch-matrix (Sur)**	
(–)168–81 (St)%	(–)26–53%	33–47%	–	**Patch-matrix (Dw)**	
(–)130–37 (Nt)%	(–)64–3%	(–)190–21%	–	**Patch-matrix (Up)**	
10–780%	92–165%	18–120%	74–733%	**Inter-patch**	**Clay**
(–)30–0%	(–)34%– (–)19	13–37%	–	**Patch-matrix (Sur)**	
(–)37–35%	(–)58–(–)26%	(–)2–47%	–	**Patch-matrix (Dw)**	
(–))68–(–)13%	(–)11–6%	20–50%	–	**Patch-matrix (Up)**	

Note "(–)" means higher value in the matrix compared to the patch
Table Abbreviations
"Inside rock" – Patches located inside rocks (the ones with two sampling plots)
"Slopped" – Patches located on hill slope far from rocks
"Adj. rock" – Patches located adjacent to rocks
"Parl. Rock" – Patches that their bottom is parallel to rock.
"Herbaceous Bm."– Herbaceous Biomass
"Patch-matrix (Sur)" – The patches averaged value vs. their surrounding matrix
"Patch-matrix (Up)" – The patches averaged value vs. their upper matrix, "Patch-matrix (Dw)" – vs. the down sampled matrix, ("Nt") – vs. the north sampled matrix and ("St") – vs. the south sampled matrix.
Note. The "Nt" and "St" abbreviation is referring only to the Parallel to rock patches group.

mixed trends. While in the "slopped patches" the higher differences were in the upper matrix, in the "Adjacent to rock patches" the higher differences were in the lower matrix.

The results in Table 1 clearly indicate that the higher differences between the patches, even the ones related to the same group, are due to local, undefined parameters affecting each patch in a different manner. In order to deal with this heterogeneity, we used the ranking analysis and widened it to the sub-patch plots (Fig 3).

The first analyzed factor is the soil moisture which is the most limiting factor in arid ecosystem. In general, the matrix has lower values than the patch plots. With regards to the sub-patches plots there was an increase in the soil moisturefrom the upper plots to the lower ones, with exception of the "slopped" group in which the lower parts were the

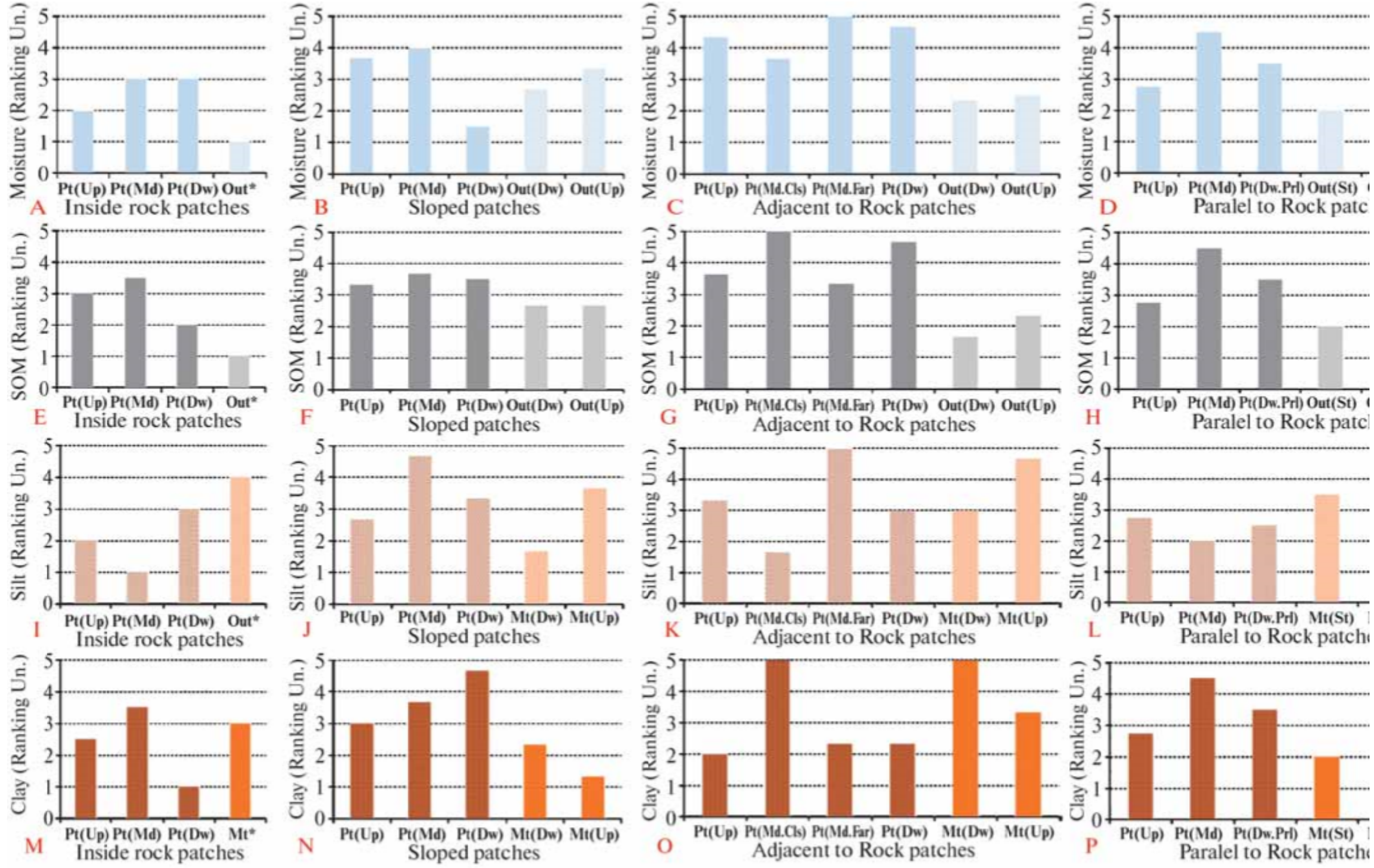

Fig. 3. Ranking values of the different soil parameters for the different patches groups.

A–D Moisture ranking values ("Inside rock", "Slopped", "Adjacent to rock", "Parallel to rock" groups, respectively). E–H SOM ranking values ("Inside rock", "Sloped", "Adjacent to rock", "Parallel to rock" groups, respectively). I–L Silt content ranking values ("Inside rock", "Sloped", "Adjacent to rock", "Parallel to rock" groups, respectively). M–P Clay content ranking values ("Inside rock", "Slopped", "Adjacent to rock", "Parallel to rock" groups, respectively).

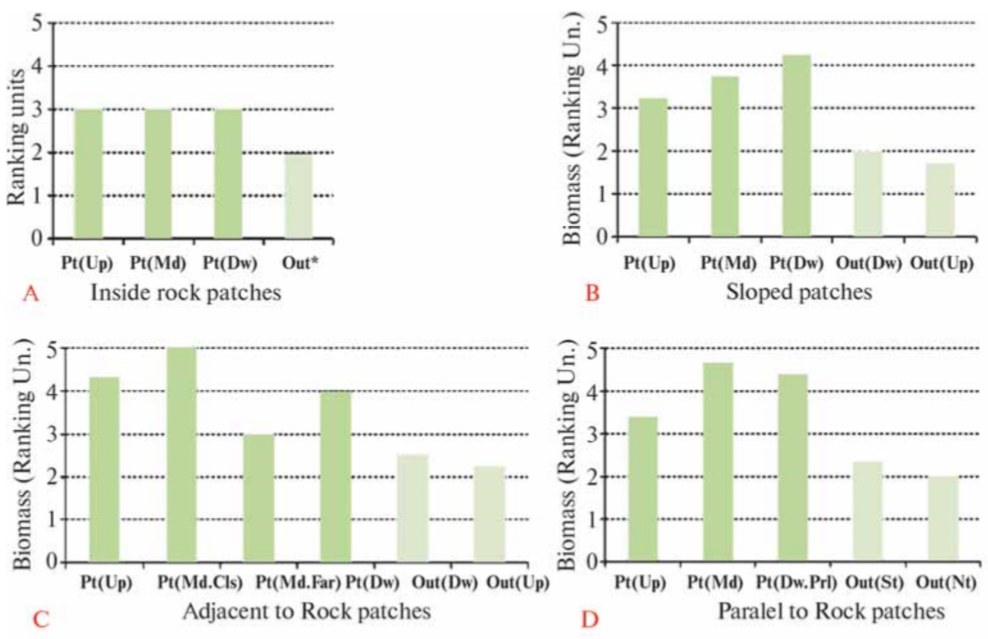

Fig. 4. Ranking values of the herbaceous biomass for the different patches groups.

A – "Inside rock", B – "Slopped", C – "Adjacent to rock" and "D – Parallel to rock" groups.

driest. Interestingly, the plots close to the rock ("Pt.Md.Close") did not have the highest values of soil moisture (Fig 3A-D).

The Soil Organic Matter (SOM) also demonstrated higher values in the lower plots of the examined patches. In the "Adjacent to rock" group the highest SOM values were at the lower part of the patch and adjacent to rock. Surprisingly, in the "parallel to rock" group the higher values were in the middle part (Fig. 3E-H).

As for the silt, the highest values were observed in the upper matrix sub-plots and in general decreased in the direction of the lower parts of patches. The higher silt values were observed in patches distanced from the rocks (Fig 3I-L).

Finally, the clay content increased in general in the descent direction in the sub-patch plots. However, in the "parallel to rock" group low values were found in the lower part of the patch parallel to the rock ("Pt(Dw.Prl)") (Fig 3M-P).

In the eyes of the land manager "the pivotal product" is the herbaceous biomass. Its values for the different sub-patches are summarized in Fig. 4. With regard to the herbaceous biomass in the "Inside rock" patches, there were no differences between the sub-patches plots. For the slopped patches there was a rise in the above mentioned value that paralleled the descent along the patch. In the "adjacent to rock patches" the higher values were located in the plots close to the rock, while the lower ones were found for the farthest from the rock plots (for the other plots no difference was observed). For the "parallel to rock" group the lowest value was at the upper part of the patch ("Pt(Up)"), and almost no difference was observed for the other parts.

After analyzing the inter-patch differences, we intersected the values of soil factors with those of the herbaceous biomass. The results are presented on Fig. 5.The soil moisture and the silt did not influence the herbaceous biomass both for the inter-patches and matrix sets, with higher deviation ("b" parameter of the linear trend line equation) observed for

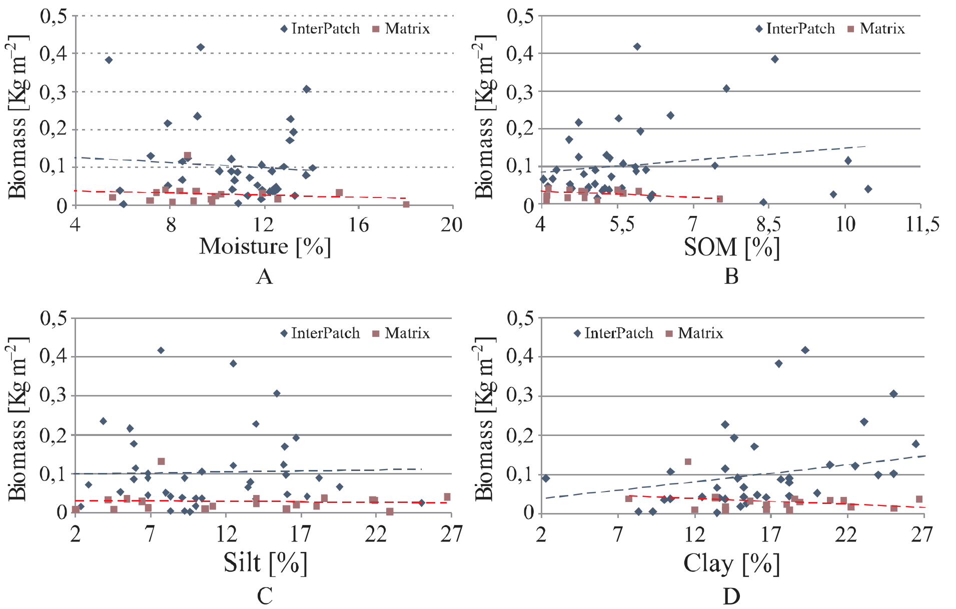

Fig. 5. The relationship between the soil parameters and the patch herbaceous biomass cover.

Rhombuses (blue) are representing the inter-patches plots and their trend line in dashed (blue). Rectangles (red) are representing the matrix plots and their trend line in dashed (red).

the inter-patch set.The SOM and clay factors had different effects on the inter-patches and the matrix plots. Whereas for the matrix plots the increase in the soil parameters did not affect the herbaceous biomass, for the patches plots the soil factors had a positive impact on it.

The first mapped parameter in patch Nr. 10 was the soil moisture. Its highest values were nearby the rocks and the biggest shrubs at the east and north edges of the plot, whereas the stream area had the lowest ones. According to the SOM map, the higher SOM values are found in small area around the sampling plots and then become blended and undetectable in the values category of the main stream. The clay map demonstrated accumulation inside the patch, whereas outside it and adjacent to the rocks the clay values were lower. The spreading map of 2nd stoniness ("Y" diameter between 0.36 and 1.44cm) demonstrated concentration in the lower part of the patch and in the upper matrix close to the patch.

The soil' litter (composed mainly of roots and humus, and to a lesser extent of flora slices due to grazing) was mainly spread near the *P. tortuosus* plants. Lesser quantity of the litter was found in the patch "body", and the lowest litter values were found in the downhill part of the patch. The herbaceous biomass values were high near the shrubs, but our analysis was not sensitive enough to detect changes in the biomass inside the patch "body".

In this work we investigated the abundance of several soil factors inside the given patches and their surrounding matrix located in slopped rocky areas. This was done in order to assess their effects on the herbaceous biomass of the examined areas. From the scientific documentation it is agreed that the most important factor effecting patch fertility in arid shrublands is the soil moisture (with regard to the term "arid" we also refer to the semi-arid areas). Although differences in the soil moisture values were found to be as expected according to Katra et al. [2008] (the higher values near the rocks, and lower ones down the patch), and paralleled the pattern of changes in the herbaceous biomass values, still these differences were not correlated in a statistically meaningful manner (Fig 5A). The

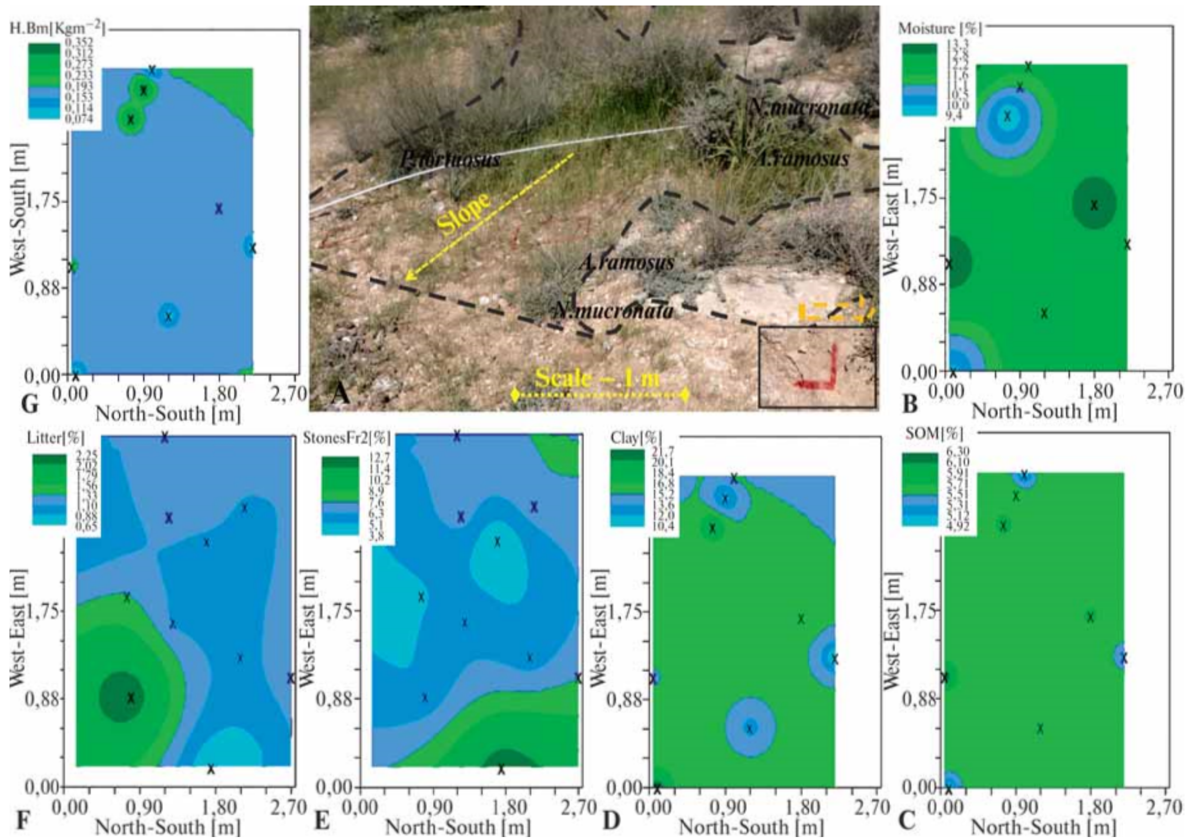

Fig. 6. The spreading maps (based on kriging analysis) of different parameters in patch Nr. 10.

A – The scaled photo of patch Nr. 10. (Photo by A. Mor-Mussery, March 2014).

**In small frame the red painted grids' start point on the adjacent rock . *Dashed grey represent the patch boundaries (the fertile area excluding the rocks)*

B – Spreading map of soil moisture (%), March 2014. C – Spreading map of Soil Organic Matter (%), March 2014. D – Spreading map of clay content (%), March 2014.

E – Spreading map of litter (%), August 2014. F – Spreading map of stoniness 1.4–0.36 cm (%), August 2014. G – Spreading map of herbaceous biomass (Kg m^{-2}), March 2014 lack of correlation in the case of annuals could be explained by the sensitivity of the annuals to the high moisture levels (as found in this study, and can be explained by the closeness of the last rain event to the time of the field study and its high intensity (12-15.3.2014 – 81 mm). This high moisture caused the soil to be over-saturated as demonstrated by lack of additional herbaceous growth during the sampling time [McMichael et al 2006]. Thus, later in the season, it would be expected that the soil moisture values will be more tightly correlated with the herbaceous biomass [Schwinning et al. 2004].

Our findings on annuals are in contrast to the tight and time independent correlations between the soil moisture and the shrubs' characteristics that were previously documented by Pariente [2002],indicating that shrub's characteristics are less affected by the sampling schedule than those belonging to the annuals.

From all the examined parameters the clay and SOM contents are the only ones that positively correlated (although not tightly) with the amount of the measured herbaceous biomass [Tongway and Ludwig 1996]; (Fig 5B& D). This could point to a possibility that combinations of the above mentioned and additional factors (soil, geographical, chemical etc.) should be examined in the future as candidates influencing the inter-patch fertility [Li et al 2008]. From the second set of measurements implemented on patch Nr. 10 (the soil stoniness and litter contents), negative correlation has been visually observed between the stoniness level of the second fraction, and the herbaceous biomass. However, further research is needed to attest these correlations.

The biggest challenge of this study was defining the differences between the inter-patch parts and transforming them into comparable values. For this purpose, four types of analyses based on work of Lloyd [2010] were specifically designed for this study. The first one (Table 1) is based on the comparisons of the actual values. Its biggest advantage is its reliability, but its main drawback is the high range of results. Thus, in table 1, we preferred to present the ranges and not the averages (could be misleading). The second type of analysis (presented in Fig. 3, relies on Hamby [1994] principles) is based on ranking the actual values of the examined factors. In such a way this methodology enables, on one side, to gather the combined values from patches located in different locations, and on the other side, to correlate the factor values to the inter-patches spatial differences. The third analysis is aimed at studying the interactions between the soil parameters and herbaceous biomass (Fig. 4), and is based on constructing regression that could be also used for studying the interplay between the above mentioned factors in patches' parts. Interestingly, we found that the examined factors affect differentially the herbaceous biomass in plots located inside the patch and in the matrix. This hints to a possibility of combined landscape effects.

As opposed to the former analyses that are based on ordinary statistics with fitness to spatial terms, the forth analysis performed by us belongs to the geo-statistics group. This type of analysis takes into concern not only the factor values, but also their locations in coordinates grid (we used the "kriging" type of analysis due to its relatively high frequent use in former ecological studies [Turner 2005]). The resulted spreading maps of the different factors in patch Nr. 10 demonstrated both the advantages and the drawbacks of kriging. Although the kriging analysis is based on "constrained" spatial analysis without taking into concern natural barriers or streaming paths such as rocks, it succeeded in drawing the actual boundaries of patch Nr. 10 based on the clay content values. This was also in agreement with the results of the former analyses. However, the "kriging" was less informative in the case of herbaceous biomass and SOM, which could be explained by the minor changes in their values in space [Bishop and McBratney2001]. With regard to the herbaceous biomass and SOM, these results were in controversy to those obtained by the former types of analyses which succeeded in identifying the differences between their values and the correlation between the factors. Overcoming of the above mentioned discrepancy could be achieved by visual comparisons between the spreading maps of the two sets (March and September 2014). Such a comparison demonstrated the wider distribution of values categories in the second set. The wider distribution could be explained by the higher number of samples (11 vs. 9), and the higher spatial distribution of the sampling locations as compared to the first set [Price et al 2000]. These factors (spreading and number of samples) should be taken into concern when choosing the sampling locations for the kriging analysis. An important advantage of the geo-statistics analyses is their ability to compare values that were taken in different locations and timing, such as the parameters that were taken in March and September in this study [Mor-Mussery et al. 2013a]. Of note, for this study we used visual examinations of the spreading maps, but statistical examination could be done by using the "Multi-layer" analysis [Mor-Mussery et al 2014b].

CONCLUSION

This paper is the first attempt to define and assess the relationships between different soil factors and herbaceous cover inside the patches (located in hilly and rocky topography) and with regard to their surrounding matrix. The dynamic and mixed effects of these parameters on the herbaceous biomass demonstrate the timing and the location importance, with regard to the measurements. For defining these dynamic interactions several analyses were used, part of which were unique to this study. Each of them highlights one aspect of these interactions, but only their integrative application (based on conventional, ranking and geo-statistics analyses) can advance our understanding about these processes and will allow in turn, better sustainable management of similar landscapes.

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